Hindawi
International Journal of Chemical Engineering
Volume 2022, Article ID 4413617, 13 pages
https://doi.org/10.1155/2022/4413617

Research Article

Assessment on Performance and Emission Characteristics of the CRDI Engine Fueled with Ethanol/Diesel Blends in Addition to EGR

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Received 16 April 2022; Revised 5 July 2022; Accepted 12 August 2022; Published 7 October 2022

Academic Editor: Witold Kwapiński

In this research, the CRDI engine characteristics were analyzed with the aid of exhaust gas recirculation rate (EGR) adoption fueled with ethanol blends. The test fuels were the various blends with ethanol, such as (10% of ethanol + 90% of diesel) E10D90 (20% of ethanol + 80% of diesel), E20D80, and (30% of ethanol + 70% of diesel) E30D70. From the results, it was revealed that performance characteristics were reduced when using a higher concentration of the alcohols mixed with diesel fuel. The blend E30D70 showed that brake thermal efficiency (BTE) without EGR drops by 3.8%, increased by 9.14% of BSFC, a 9.25% decrease in oxides of nitrogen emissions, and slightly decreased CO and HC emissions compared to baseline diesel operation at 60% load condition. The blend E10D90 with 20% EGR shows the highest BTE of 8.87% when compared with base fuel, due to proper fuel mixture taking place in the inlet manifold. The results indicate that the engine runs smoothly, and E30D70 has chosen an optimum blend. A further experiment was performed using E30D70 with different rates of exhaust gas recirculation system. The addition of exhaust gas recirculation with E30D70 in the common rail diesel engine exhibits oxides of nitrogen emission, but in contrast, it was noticed to have inferior performance characteristics and drastically decreased HC and CO emissions. The hydrocarbon emission decreased E10D90, E20D80, and E30D70 at 60% load condition by 21.42%, 37.38%, and 48.76%, respectively. The blends E10D90, E20D80, and E30D70 decreased carbon dioxide by 7.9%, 30.08%, and 31.98%, respectively. The maximum reduction of NOx emission was observed at about 51.06% at an EGR rate of 20% with E30D70.

1. Introduction

The use of a conventional CI engine is increasing daily in the agriculture automotive sectors due to the greater BTE. They are increasing the automobile industry because of human needs, and there is an increase in the vehicle population. The forceful utilization of diesel and petroleum for transportation prompts ecological contamination and the augmentation of petroleum-based products. Because of the expanding demand and consumption of nonrenewable energy sources prompt an ascent in the cost of crude oil products in the world retail [1, 2]. The conventional CI engine produces higher thermal efficiency and expels toxic exhaust gases such as CO, CO_2, NOx, and smoke, affecting human health and environmental conditions [3, 4]. Some of the sulphur-based emissions come from the CI engine, causing some serious issues in the human health respiratory disease systems and cancer [5, 6]. Much research have been followed by many methodologies to reduce toxic exhaust gases from the CI engine.

The alcohol has a lower CN, lower heating value, and greater latent heat of evaporation (LHE), which solves problems in the diesel engine. The diesel fuel is mixed with the alcohol and used in the conventional CI engine. The alcohols such as ethanol, methanol, and propanol have a lower carbon content because of their lesser heating value. The molecular structure contains three carbon chains known as greater carbon alcohol and has superior fuel properties [7, 8].

The properties of higher alcohols are almost near to gasoline fuel. The alcohols are easily mixed with the diesel and lower alcohol blends are stable for a long time. Many types of research proved and ran the engine successfully without any fuel alternation of the diesel engine to improve its engine's efficiency [9–11].

Many kinds of research were found to show that the higher alcohol concentration mixed with the diesel shows good performance and reduces the emission characteristics of the CRDI engine. In this investigation, the three different alcohol types are used in the CRDI engine ethanol, methanol, and butanol mixed with the mineral diesel and prepared the blend'diesohols. The diesohols were used in the CRDI engine to achieve higher BTE when compared with diesel fuels. When adding the alcohol into the diesel fuel to increase the BTE and reduce the nitrogen and particle matter oxides when correlated with the base fuel at 100% of load condition. The methanol and ethanol are mixed with the diesel to show the optimum result compared with the other alcohol blend types. The highest BTE is achieved using ethanol and methanol mixed with diesel fuel and reduction of oxides of nitrogen, soot particles, and particle matter at full load conditions [12].

The ethanol and isopropanol blend with fossil diesel is used as fuel in the CRDI engine. The two blends were prepared as diesel 85% + ethanol 15% and diesel 85% + isopropanol 15% to run with the CRDI engine. The engine operated with four load conditions and three different operating speeds. Adding alcohol into the diesel fuel observed greater BSFC and cylinder pressure than adding alcohol into the diesel fuel. The alcohol mixed with the diesel shows higher brake thermal efficiency, carbon monoxide, and nitrogen oxides when correlated with base fuel. The diesel blended with alcohol has little influence on carbon dioxide emissions. The ethanol and isopropanol mixed with the diesel fuel show similar results in performance, combustion, and emission characteristics [13].

The effect of *n*-butanol is used in the common rail diesel engine. The n-butanol is mixed with diesel fuel at various proportions, namely B5, B10, and B20, and they are used as fuel in the CRDI engine to investigate engine characteristics. The engine is operated with four different load conditions and three different operating speeds. The blend B10 shows emitted greater nonregulated pollutants when correlated with the diesel fuel under low load conditions. The blend B10 shows a drastic reduction of particle matter by 31.21% when correlated with the base fuel. The B20 blend achieved the optimum results, showing higher BTE and decreasing the nitrogen oxides, exhaust gas temperature, and particle matter emission when correlated with the diesel fuel [14].

The acid oil methyl ether is used in the CRDi diesel engine. The vegetable methyl ether is mixed with the diesel, and alcohol was prepared for the fuel blend of AOME70% + D15% + E15%. The vegetable methyl ester blend with ethanol exhibited lower BTE and NOx emissions than the neat vegetable methyl ester. This blends also showed higher HC, smoke, and CO emissions than diesel. When increasing the ethanol concentration into the biodiesel-diesel blends, it shows a drastic reduction in BTE and decreases the emission characteristics like HC, CO, and NOx when compared with the diesel fuel [15].

Much research was carried out on the experiments with different alcohol blends with the CRDI engine. The higher concentration of alcohol blended with diesel shows greater enhancement in BTE and decreased carbon monoxide, the opacity of smoke, and increased nitrogen oxides compared with diesel fuel. The nitrogen oxides are increased when using a higher concentration of alcohol to introduce the exhaust gas recirculation.

The Pentanol mixed with the base fuel was prepared for the various blends P10, P20, and P30 in the CRDI engine with EGR. The three types of fuel blends were prepared: pentanol 10% + diesel 90% (P10), pentanol 20% + diesel 80% (P20), and pentanol 30% + diesel 70% (P30). The exhaust gas recirculation rate was used at 10% and 20% in the investigation. The blend P30 shows the highest BTE, BSFC is achieved at 4.23%, 10.54% a drop in nitrogen oxide, and slightly higher carbon monoxide and hydrocarbons than diesel fuel. It is clearly shown that the higher alcohol concentration blended with diesel fuel achieved optimum results, and the engine runs smoothly at 60% load condition [16].

The alcohol pentanol was mixed with the diesel and was prepared. The fuel blends are P10, P20, P30, and P40. The exhaust gas recirculation rate was used at 10% and 20% in the investigation. To increase the alcohol concentration, the BTE is decreased, which raises the BSFC compared with base fuel without EGR. The best blend of pentanol 30% + diesel 70% (P30) shows a decrease in BTE, increased BSFC, a drastic reduction of nitrogen oxides, and slightly decreased hydrocarbon and carbon monoxide when compared with the base fuel [17].

Both different types of alcohol are utilized in the CRDI engine. Ethanol and butanol are used as alcohols in the CRDi diesel engine. The three types of fuel blends were prepared, the B15, E15, and B40. The exhaust gas recirculation rates of 10%, 20%, 30%, and 40% were used in the investigation. In blends, B40 achieved the highest BTE. When increasing the EGR rate, gradually decrease the combustion pressure, heat release rate, and temperature. CO emissions were linearly increased with an increase in EGR rate up to 30% beyond this slight decrease. NOx emissions were continuously reduced with an increase in the EGR rate [18]. *N*-pentanol and isopropanol are used in the CRDi diesel engine. The *n*-pentanol and isopropanol are mixed with diesel and were prepared, the blends are 20% *n*-pentanol + 80% of diesel, and 20% isopropanol + 80% of diesel. The blend of 20% isopropanol + 80% of diesel shows the greater ID because of the lower CN and lengthen the combustion duration. The blend 20% isopropanol + 80% of diesel shows lower peak pressure-temperature than other blends. The oxides of nitrogen are increased by 20% isopropanol + 80% of diesel than base fuel. The lowest nitrogen oxides are observed in the blend of 20% *n*-pentanol + 80% of diesel with an exhaust gas recirculation rate of 20% compared with the other test fuels [19].

From the above literature survey, it was observed that blending diesel with a higher concentration of alcohols showed better performance and emission characteristics. The oxides of nitrogen were reduced when using a higher concentration of alcohol in the CRDi diesel engine. Based on the above study, the main objectives of this present study is (i) to investigate the CRDi engine characteristics operated with ethanol and diesel. The ethanol blends to be used in this experiment, namely E10D90, E20D80, and E30D70. (ii) To study the effects of EGR adoption along with ethanol and diesel blend on the CRDi engine to further minimize the NOx emission.

2. Material and Methods

The experimental work was carried out on the CRDI engine made by Mahindra Maxximo cab, as shown in Figure 1. The CRDI diesel engine was connected to the EUC, which regulates the working boundaries of the CRDI. For stacking reasons, a current swirl dynamometer was coupled with the base engine to measure and control the brake torque. Subtleties of the test motor are classified, as shown in Table 1. The illustrative portrayal of the ideal test arrangement created appears, as shown in Figure 1. The AVL 444 gas equipment was utilized in the investigation of tailpipe discharge. A detailed description of the AVL 444 gas equipment has appeared in Table 2. Thermocouples of the K- type were utilized in the estimation of temperature. The turning encoder was utilized to gauge the engine speed, and the deliberate estimation of the engine's speed was shown in RPM on a computerized marker. HPP was utilized to flexibly fuel HPCRIS. HPP separates the gasoline from the tank and delivers it to CRIS via the channel, maintaining a consistent CRIS weight regardless of stacking quality. Agreeing to the stacking quality, the solenoid valve regulates the amount of fuel provided to the fuel injector. The streaming pace of the fuel was estimated physically by utilizing a burette and stopwatch. A burette was connected straightforwardly to the fuel tank.

2.1. Tested Fuels. In this research work, pure 99.99% ethanol is used for the experimental investigation, and it was bought from JSHME chemicals in Chennai. The three ethanol and diesel blends were prepared for this investigation, namely (10% of ethanol + 90% of diesel) E10D90, (20% of ethanol + 80% of diesel) E20D80, and (30% of ethanol + 70% of diesel) E30D70. The blends were prepared with a mechanical stirring process to maintain a temperature range of 60°C and a constant 1500 rpm speed. Afterward, the prepared fuel blends were checked for phase stability at eight hours. The blends have ensured homogeneity at the same mentioned time. Table 3 shows various alcohol fuel blends and Table 4 shows fuel properties. Fuel preparation is depicted in Figure 2.

3. EGR

The main purpose of EGR is to be utilized to decrease the oxides of nitrogen. EGR system recirculating some parts in the tailpipe emission push into the intake manifold and burnt gases has entered with the fresh air [22]. Before entering into the intake manifold, the burnt gases allow them into the intercooler to cool the intake charge. The EGR system reduces combustion temperature and pressure because of the supply of high SHC of burnt gases. The formula for the EGR rate is

$$\text{EGR Rate} = \frac{\text{Mass of air without EGR} - \text{Mass of air with EGR}}{\text{Mass of air without EGR}}. \quad (1)$$

According to the necessity, the user needs to give the inlet; the gap modulates the electronic control unit's signs as per given information, which regulates the aperture or shutting of the pneumatic valve.

3.1. Uncertainty Analysis. The uncertain investigation is utilized to increase the accuracy of the measuring instruments. The uncertainty analysis depends on measuring instruments, working atmosphere, vibration, experimental method, and human errors [25]. The procedure for conducting the uncertainty analysis first starts with starting the engine run for half an hour and recording reading with equipment and software. Again, four to five times, the experiments were conducted repeatedly and the average value for the reading was taken. Table 5 shows that the AVL gas analyzer and uncertainty analysis is shown in Table 6.

3.2. BTE. The variations of BTE with BP in the absence of EGR are shown in Figure 3. The lower increment noted at the starting load condition means that further condition of the load is higher and the BTE is also greater due to improving the combustion efficiency. At full load conditions, a higher concentration of alcohol blends was noticed with lower BTE than fossil diesel [26]. The decreased brake thermal efficiency at 60% of the condition of load for E10D90, E20D80, and E30D70 is 1.98%, 3.89%, and 4.12% sequentially when correlated with the diesel fuel because of the LHV properties of alcohols in greater alcohol concentration in the diesel blends, which affect the postcombustion temperature that conclusions in constrains of chemical reaction of HC. This would be the main reason for inferior

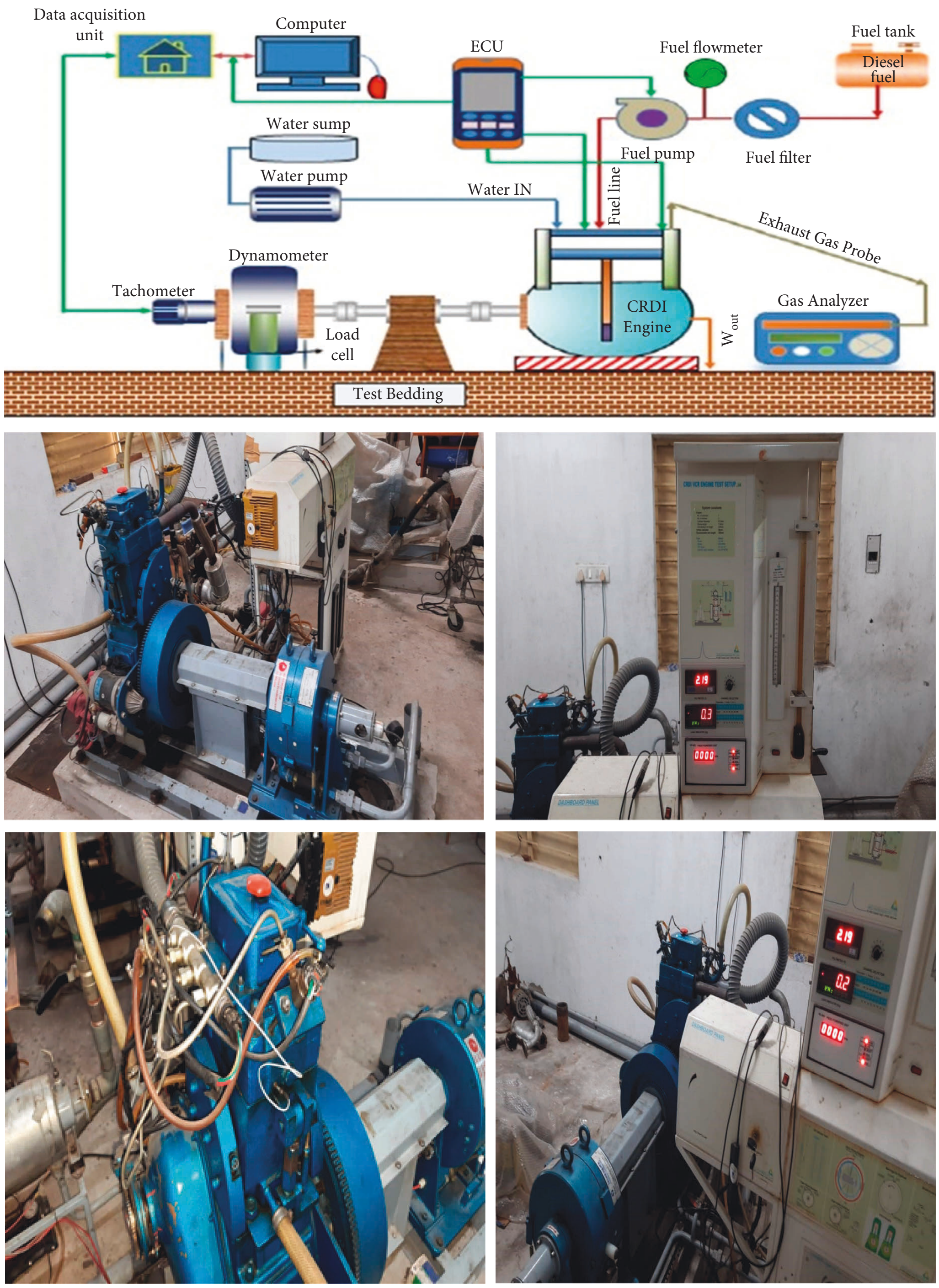

Figure 1: CRDI engine.

combustion happening while doping alcohol in diesel. The latent heat of ethanol's vaporization is about 850 kJ/kg, which results in a greater amount of heat energy being absorbed in the combustion chamber during the combustion stroke. Moreover, a few fractions of the amount of water content present in fuel blends leads to a similar impact as ethanol blends [27]. The less CN-rated ethanol could result in a high ID period, which causes delayed start of burning. The greater measure of heat is the engine parts' loss due to the long span of ignition delay during the combustion process, which leads to less BTE when correlated with the base fuel.

The consequence of EGR at 60% load on brake thermal efficiency with ethanol/base fuel blend is shown in Figure 4. The exhaust gas recirculation has shown on a negative impact on blends when correlated to without EGR condition. The BTE of blend E30D70 with EGR 10 and 20% was shown to be 5.30% and 16.98% less than without the EGR condition. On the whole, it was noticed that the addition of the EGR affects the combustion reaction and oxidation of

Table 1: Performance and emission characteristics of various alcohols bend with diesel.

Test conditions	Blend	Performance characteristics		Emission characteristics				Ref./year
		BTE	SFC	HC	CO	NOx	PM	
Variable speed, constant load	5% ethanol + 95% waste cooking oil biodiesel	↑	↓	↔	↔	↔	↔	[20]/2011
	10% ethanol + 90% waste cooking oil biodiesel	↔	↔	↔	↔	↔	↔	
	15% ethanol + 85% waste cooking oil biodiesel	↔	↔	↔	↔	↔	↔	
Constant speed, variable loads	5% ethanol + 95% diesel-biodiesel blend	↔	↔	↔	—	↔	—	[21]/2017
	10% ethanol + 90% diesel-biodiesel blend	↔	↔	↔	↔	↔	—	
	15% ethanol + 85% diesel-biodiesel blend	↔	↔	↔	↔	↔	—	
Variable speed	20% ethanol + 80% sunflower biodiesel	↔	↔	↔	↔	↔	↔	[22]/2010
Variable speed, variable loads	5% ethanol + 95% diesel	↔	↔	↔	↔	↔	↔	[23]/2008
	10% ethanol + 90% diesel	↔	↔	↔	↔	↔	↔	
Variable speed, variable loads	3% ethanol + 12% methyl soyate + 85% diesel	—	↔	↔	↔	↔	↔	[24]/2005
	4% ethanol + 16% methyl soyate + 80% diesel	—	↔	↔	↔	↔	↔	
Variable speed, variable loads	5% ethanol + 20% methyl soyate + 75% diesel	—	—	↔	↔	↔	↔	[6]/2006

Table 2: Engine set up.

Engine specification	Engine details
Make	Mahindra and mahindra
Model	Maxximo
Capacity	900 cubic centimeters
Number of cylinder	Two
Speed	3600 rpm
IT	12-degree bTDC
Bore	105 mm
Stroke	130 mm
Displacement	4.5 L
Rated power	113 kW
Torque	520 N-m
IP	1000 bar
Dynamometer	Eddy current
Compression ratio	18.5 : 1

hydrocarbons, which may result in a decrease in BTE [28] (see Table7).

3.3. BSFC. The variations of BSFC with break power are absent from EGR, as shown in Figure 5. The BTE is inversely proportional to the brake specific fuel consumption. It is noted that for all the tested fuels the BSFC curve is decreased at full load conditions. The BSFC for ethanol/diesel for all the blends is higher when correlated with the base fuel because of the lower CN and heating value, as they produce the same power and more amount of the fuels that are required compared with mineral fuel. The existence of oxygen particles in ethanol leads to a reduction in its heating value. Greater amount of heat is absorbed during combustion because of the increased LHE in the ethanol present in the blend that results in flame quenching and lower combustion [29]. The existence of a lower amount of water molecules in the fuel absorbs the temperature of the combustion. This is significant because the BSFC has been increased for ethanol/diesel blends. At 60% of load condition, the brake specific fuel consumption of the various blends E10D90, E20D80, and E30D70 is increased by 3.93%, 7.39%, and 8.87% sequentially when correlated with the base fuel. The lower cetane number of ethanol represents the longer ID, which

Table 3: Various alcohols fuels blends [16].

Properties	Diesel	Propanol	Butanol	Pentanol	Ethanol
Density (kg/m^3) at 15°C	836	804	810	815	782
Viscosity at 40°C	2.74	1.78	2.24	2.92	1.22
LHV (MJ/kg)	43.19	31.89	34.12	35.32	27.87
LHE (kJ/kg)	284	728	583	381	920
Self-ignition temperature	287	351	346	348	424
Cetane number	54	12	17	20	9
Carbon (%) (wt)	87	60	65	69	58
Oxygen (%) (wt)	0	27	22	19	35
HC (%) (wt)	14	15	15.2	15.8	13

Table 4: Fuel properties.

Properties	Diesel	E10D90	E20D80	E30D70
Density (kg/m^3) at 15°C	836	832	829	827
Viscosity at 40°C	2.74	2.76	2.78	2.83
Cetane number	54	51	49	47
LHV (MJ/kg)	43.19	41.78	40.76	39.89
Oxygen (%) (wt)	0	4	5.1	7.3

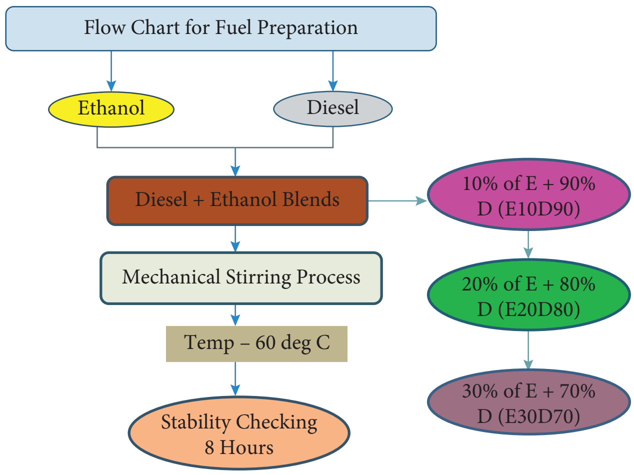

Figure 2: Fuel preparation.

Table 5: AVL exhaust gas analyzer.

Parameters	Measuring value	Resolution
Oxygen (vol)	0–21%	0.01%
Carbon monoxide (vol)	0–11%	0.01%
Carbon dioxide (vol)	0–20%	0.1%
Hydrocarbon (ppm)	0–20000	1
Oxides of nitrogen (ppm)	0–5000	1

Table 6: Uncertainty analysis.

Parameters	Uncertainty analysis (±)
CO	0.2
Carbon dioxide	0.3
Hydrocarbon	0.9
NOx	0.2
Time	0.9
Load	0.2
BP	0.3
FC	1.2

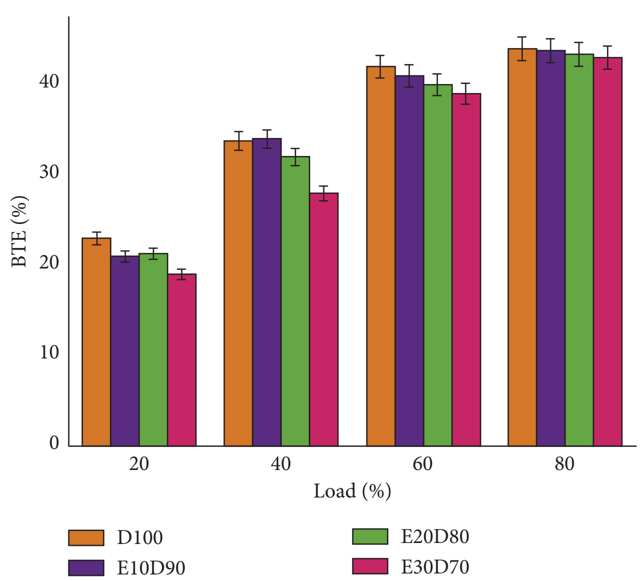

Figure 3: Variation in BTE with load.

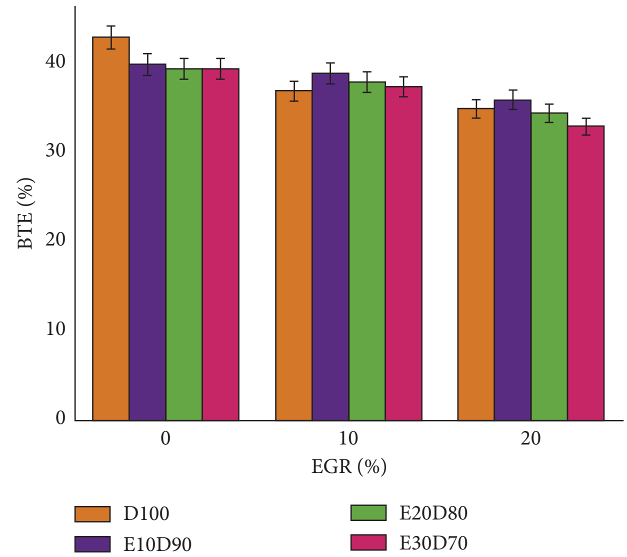

Figure 4: Variation in BTE with EGR (0%, 10%, and 20%) at 60% load.

Table 7: Comparison of E30D70 vs. E10D90.

Characteristics	Blends	EGR10% (%)	EGR20% (%)
BTE	E30D70	−5.30	−16.89
HC	E30D70	−18.78	−37.89
CO_2	E30D70	−6.8	−9.8
NOx	E30D70	−24.70	−51.06

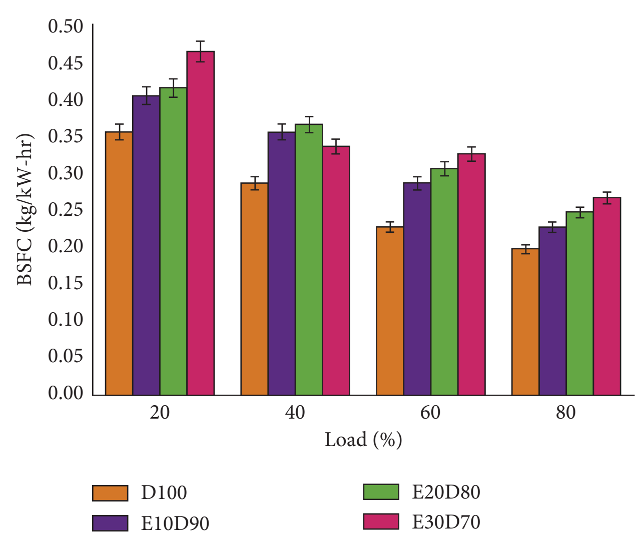

Figure 5: Variation in BSFC with load.

results in a greater combustion duration because of the greater duration of combustion that causes more amount of heat to be transferred to the engine parts. This is the main reason for low cylinder temperature and cylinder pressure, resulting in increased BSFC [30]. The effect of exhaust gas recirculation at 60% of the load on BSFC with ethanol mixed with diesel fuel blend is shown in Figure 6. The exhaust gas recirculation has a negative effect when compared with the

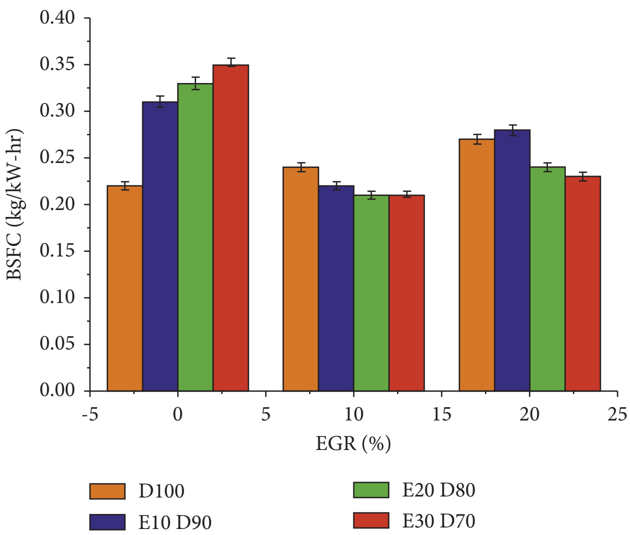

FIGURE 6: Variation in BSFC with EGR (0%, 10%, and 20%) at 60% load.

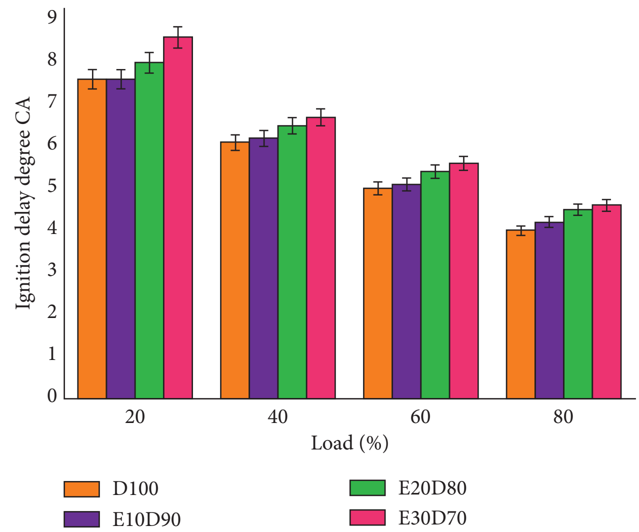

FIGURE 7: Ignition delay.

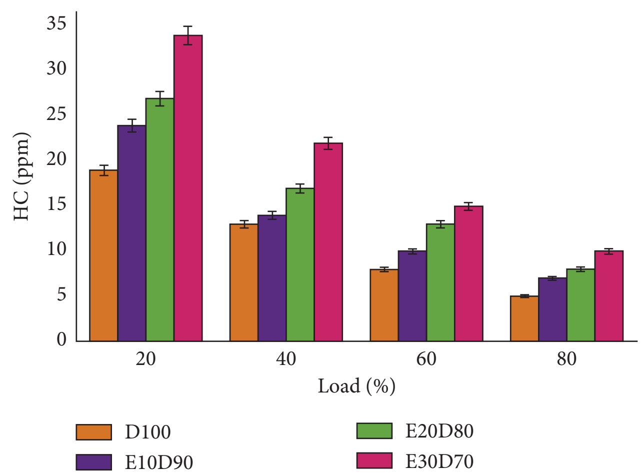

FIGURE 8: Variation in HC with load.

absence of EGR. The BSFC is higher when the EGR rate is increased due to the combustion chamber temperature being reduced and the combustions efficiency is also reduced. When the addition of EGR and higher alcohol in diesel fuel lengthens the combustion beyond TDC due to ethanol's lower cetane value, these results trigger the heat loss from the combustion and more fuel consumption, producing the same power. The BSFC of the ethanol/diesel blend with the absence of EGR is 2.89% and 11.83% less for E20D80 at 10% EGR and E10D90 at 20% EGR.

3.4. Ignition Delay. The timing among the start of the injection and the initial stages of burning is known as ID, and Figure 7 shows ignition delay. The ignition delay depends upon the cetane number of the fuel. The lower cetane number leads to a longer ID and poor performance. A greater cetane number leads to a shorter ID and better performance of the engine. To increase the engine load, the engine temperature is also increased. It caused an increase in the temperature inlet charge that resulted in a decrease in the ID. From Figure8, it is observed that the higher additives of concentration alcohol show the outcomes of longer ID because of the lower CE. The greater ID is observed for E30D70 tested fuel, which is 8.43°CA, 7.21°CA, 4.98°CA, and 4.91°CA at 20%, 40%, 60%, and 80% condition of load sequentially. Due to the oxygen present in the fuel, the lower cetane number and a small quantity of the water in the ethanol absorbed a huge measure of heat to evaporate through combustion, which causes a higher ignition delay. The consequence of EGR at 60% load on ignition delay with ethanol/base fuel blend is shown in Figure 9. The exhaust gas recirculation has shown a negative impact on blends when correlated to without EGR condition. When the percentage of EGR is increased, the ignition delay is increased when compared with base fuel.

3.5. HC. The variations of HC with load in the absence of EGR appeared in Figure 8. HC is decreased due to the complete combustion taking place during the combustion process at full load condition. The hydrocarbon content of blends E10D90, E20D80, and E30D70 at 60% of the load is 21.42%, 37.38%, and 48.76% and is comparatively higher than diesel fuel. It is indicated that the higher concentration of alcohol observed higher HC emissions when compared with other tested fuels. The high concentration of alcohol observed high HC emission at all load conditions because of the longer ID period, less CN, and greater LHE of ethanol. The combustion duration is increased [31]. The presence of a small amount of water and oxygen availability affects the self-ignition property and produces the quenching effects in the engine cylinder. Due to the greater ID, more fuels take longer to evaporate resulting in higher HC emissions. The addition of exhaust gas recirculation exhibits a little increment in the HC emission at 60% of the load conditions is shown in Figure 10. The HC emission of the blend E30D70 at 10% of the EGR rate is observed to be 18.78% and 37.89%

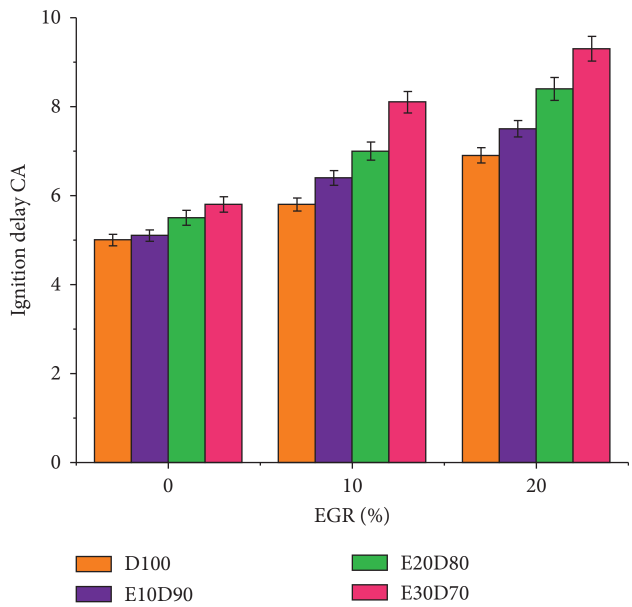

Figure 9: Variation in ID with EGR (0%, 10%, and 20%) at 60% load.

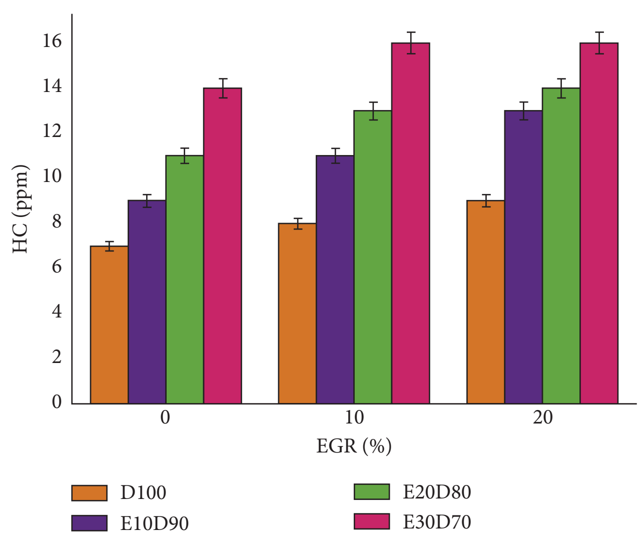

Figure 10: Variation in HC with EGR (0%, 10%, and 20%) at 60% load.

higher than the 20% of EGR with E30D70 and without EGR of E30D70, respectively. The increased combustion duration affects the premixed combustion due to the high specific heat of burnt gases when adding the EGR [32].

3.6. CO. The variations of CO with load in the absence of EGR are shown in Figure 11. The main reason to form the CO emission is low combustion temperature, less reaction time, and rich mixture during the combustion process. When starting load conditions, the CO emissions are high and increase the engine load. The CO emissions have also decreased. At 40% of load conditions, the blend E10D90 emits lower CO emissions than other tested blends.

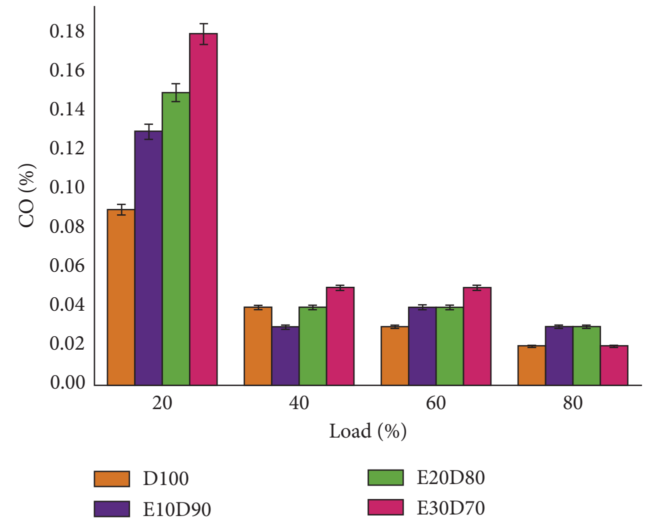

Figure 11: Variation in CO with load.

Because of the low concentration of alcohol, the blends' presence results in improving the combustion process. The higher the alcohol concentration in the tested blend increases CO emissions because the LHV and high specific heat vaporization of ethanol affect the combustion process. The blend E30D70 shows that higher CO emissions are observed 45.73%, 34.67%, 49.89%, and 63.76% greater when correlated to neat mineral fuel at 20%, 40%, 60%, and 80% load condition. This is mainly due to the greater ignition delay, lower cetane number of alcohol, and greater LHV, which affect the hydrocarbon's chemical reaction that produces more amounts of CO emissions. More fuel was admitted into the cylinder in initial load conditions, which may result in wall quenching and lesser combustion temperature [33]. This is a significant reason that the base load condition produces high CO emissions. The effect of exhaust gas recirculation with a blend of ethanol and diesel on CO emission formation at 60% of load condition is shown in Figure 12. The inadequacy of oxygen, the partial quantity of CO_2, and H_2O present in the fresh charge mixture is the main reason for increasing CO emissions while adopting the EGR. At full load condition, the blend E30D70 indicates higher CO emissions by 34.67% than correlated with the base mineral fuel with the EGR.

3.7. CO_2. The variations of CO_2 with load in the absence of EGR are shown in Figure 13. When increasing the engine load also increases carbon dioxide. It is shown that the low concentration of the alcohol mixed with the diesel blend produces lower carbon dioxide than compared with the other two blends at 60% load condition. The blends E10D90, E20D80, and E30D70 decrease carbon dioxide by 7.9%, 30.08%, and 31.98%, respectively, when compared with the base fuel because of the presence of alcohol fuel in the blends gives more cooling effect, which suppresses the burning of fuel that results in the poor combustion process. The blend E10D90 shows the highest carbon

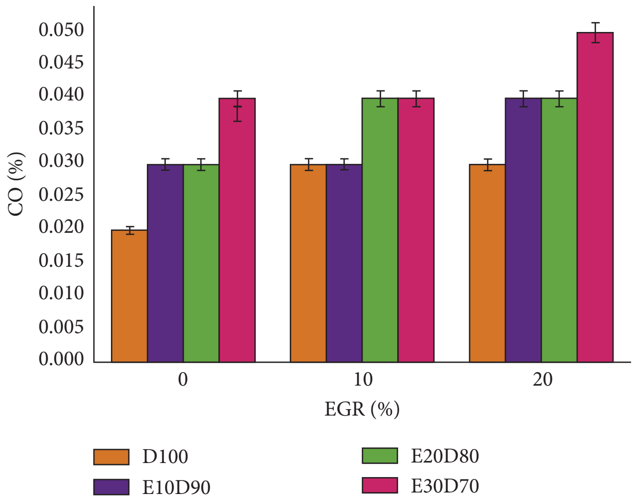

FIGURE 12: Variation in HC with EGR (0%, 10%, and 20%) at 60% load.

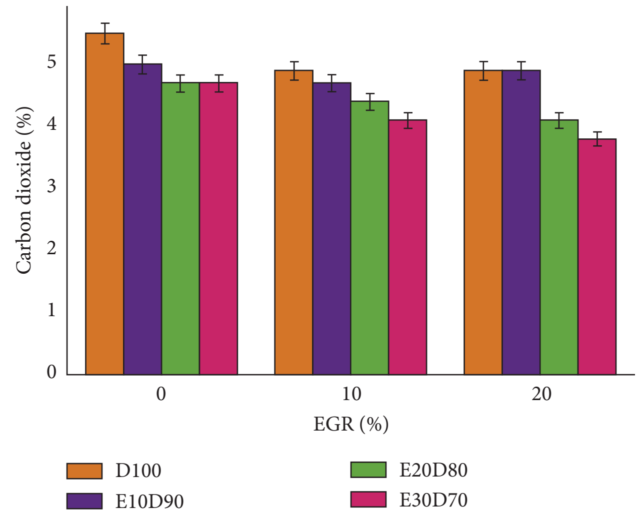

FIGURE 14: Variation in CO_2 with EGR (0%, 10%, and 20%) at 60% load.

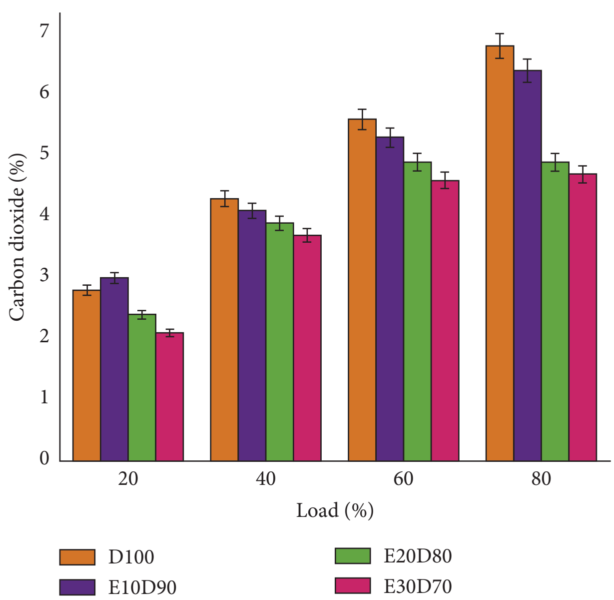

FIGURE 13: Variation in CO_2 with load.

dioxide by 32.34% more than the other two alcohol blends. The moderate cetane number and heating value of E10D90 encourage a better oxidation process, leading to a reasonable combustion process. The lower carbon dioxide is observed in the blends E30D70 by 31.98% when correlated with the mineral fuel. The greater alcohol reduces the flame temperature, provides the greater LHV, and increases the availability of oxygen content in the fuels. The addition of exhaust gas recirculation in the CO_2 emission at 60% of load conditions is shown in Figure 14. When adopting the EGR rate of 10% and 20% of load, the carbon dioxide is decreased when a higher alcohol concentration is used in the diesel engine [34–36]. The partial mixture of burnt gases into fresh air affects the postcombustion temperature due to the high specific heat capacity (SHC) exhaust gas affects the combustion reaction. The lower carbon dioxide is observed in the blend E30D90 correlated to other alcohol fuel blends, which is 6.8% less at 10% exhaust gas recirculation rate and 9.8% less at 20% exhaust gas recirculation rate compared to without EGR, which may cause less oxygen availability in the chamber and lean combustion process restricted to the promotion of CO [37–41].

3.8. NOx. The variations of NOx with load without EGR conditions are shown in Figure 15. The engine load is higher. The oxides of nitrogen are also higher because of the increased cylinder temperature during the primary combustion phase. It is indicated that temperature influences NOx formation in the IC engine. The graph shows that increasing the ethanol fraction in the tested blend linearly decreases the NO_X emission [42–45]. This is attributed to the higher latent heat of evaporation of ethanol, which suppresses the combustion temperature and additionally cools the combustion chamber. The blends E10D90, E20D80, and E30D70 decrease the oxides of nitrogen by 6.2%, 16.88%, and 17.67%, respectively, when correlated with the mineral fuel at 60% load condition. Due to the availability of ethanol in the blend has high volatile and SHC values which leads to the absorbtion of more heat from the chamber that results in lean combustion. At 20% of the load condition, the higher oxides of nitrogen were observed by 43% when correlated with the mineral fuel. This may be attributed to the lower CN; the higher LHV of ethanol reduces the cylinder temperature. The blend E20D80 and E30D70 shows decreased the oxides of nitrogen by 12.54% and 14.56% compared with the E10D90 blend [46–50]. The higher concentration of alcohol and low-temperature combustion lead to the low formation of NOx emission.

The addition of exhaust gas recirculation in the NOx emission at 60% of load conditions is shown in Figure 16. It is shown that the EGR rate is increased, and the oxides

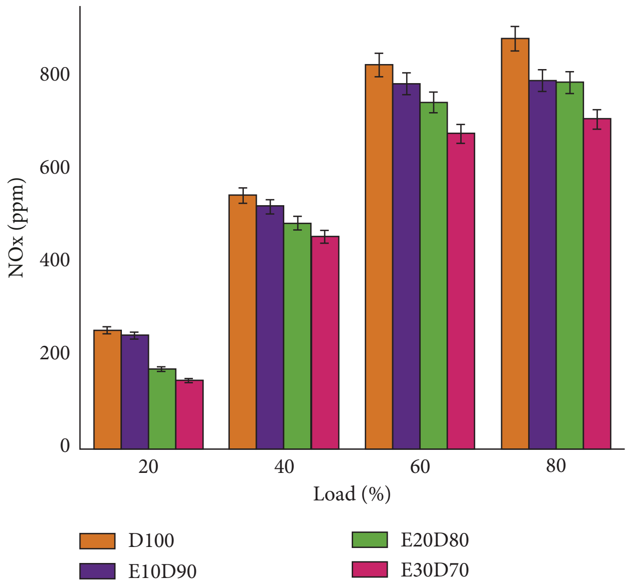

Figure 15: Variation in NO_X with load.

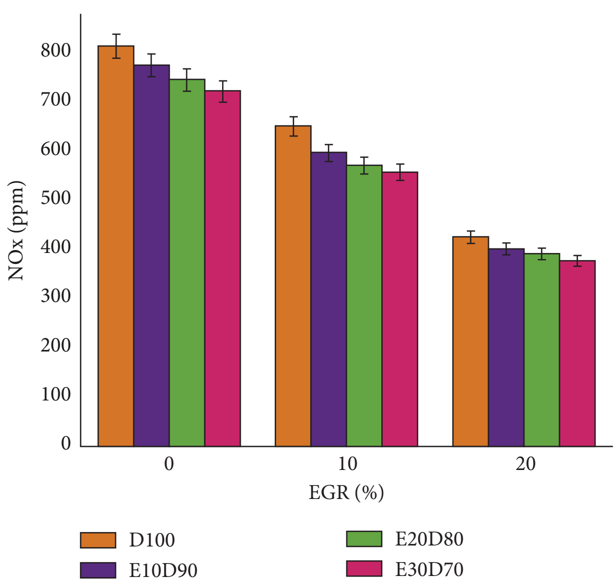

Figure 16: Variation in NO_X with EGR (0%, 10%, and 20%) at 60% load.

of nitrogen are drastically decreased. The effect of the EGR rate is the positive approach to the oxides of the nitrogen formation. At the starting load condition, nitrogen oxides are gradually increased with load from an initial condition to an 80% load condition; beyond that, NOx starts to decrease due to more fuel burns and better combustion temperature during the primary combustion phase. The E30D70 associated with EGR 20% showed the least NOx emission, which is 24.70% and 51.06% lower than the 10% and 20% EGR rates with the E30D70. This is owing to lengthening the ID period and inadequate oxygen availability in the cylinder [51].

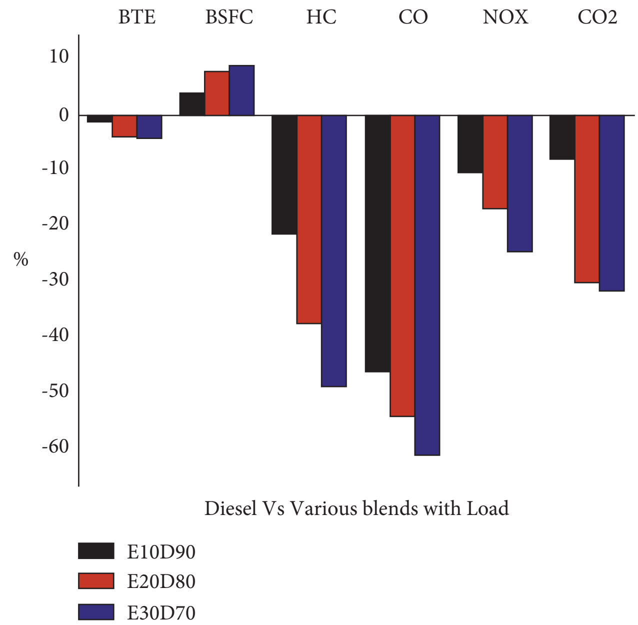

Figure 17: Overall result and discussion.

4. Conclusions

(i) The decreased BTE at 60% of the load for E10D90, E20D80, and E30D70 is 1.98%, 3.89%, and 4.12%, respectively, when correlated with the mineral fuel because of the less CN and greater LHV of alcohol concentration in the diesel decreased the temperature of the combustion. This is the main reason for reducing thermal efficiency. Moreover, when the ethanol concentration was reached beyond 30%, the thermal efficiency was reduced due to the energy value dilution of blends. The 60% load of the BSFC has increased the blends E10D90, E20D80, and E30D70 by 3.93%, 7.39%, and 8.87%, respectively of mineral fuel. The lower CN and lower energy value of ethanol represent the longer ignition delay and more fuel utilization to compensate for the same engine power. Besides that, the EGR system's adoption showed inferior thermal efficiency and fuel economy due to the high heat capacity of burnt gases that absorbed more heat from the chamber and were restricted to the complete oxidation of hydrocarbons.

(ii) The greater ID is observed for the E30D70 tested blend, which is 8.43°CA, 7.21°CA, 4.98°CA, and 4.91°CA at (20%, 40%, 60%, and 80%) load condition, respectively. Due to the lower cetane number and lesser quantity of water absorbed, a greater measure of heat to vaporize through the process of combustion may result in a higher ignition delay.

(iii) The hydrocarbon emission decreased E10D90, E20D80, and E30D70 at 60% condition of the load is 21.42%, 37.38%, and 48.76% when correlated to greater than mineral fuels. The higher concentration of alcohol observed the highest HC emissions compared with other tested fuels. When adopting the EGR, the ignition delay was drastically increased.

(iv) EGR's impact on CO formation with the fuel E30D70 was higher than other fuels at 60% of load conditions. The presence of oxygen in the explosive mixture leads to a reduction of CO_2 and H_2O in the tailpipe emissions. While adding burnt gases to a fresh combustible mixture leads to an increase in the SHC of the mixture, which results in higher carbon monoxide emissions. At full load conditions, the blend E30D70 noticed the highest carbon monoxide emissions.

(v) The blend E10D90, E20D80, and E30D70 decreased the carbon dioxide by 7.9%, 30.08%, and 31.98%, respectively, when correlated with the diesel fuel due to the high LHV of ethanol suppress the combustion temperature, which results in restriction of promotion of CO to CO_2.

The maximum reduction of NOx emissions was observed at about 51.06% at an EGR rate of 20% with E30D70. The EGR rate of 10% with E30D70 was shown to have 24.70% lower NOx than without the EGR condition. This is attributed to lengthening ID and longer combustion duration that results in low-temperature combustion. Figure 17 shows the overall result and discussion.

Data Availability

No data were used to support this study.

Additional Points

(i) Adding the nanoparticle in to the fuel to enhance the performance and reduced the emission characteristics. (ii) Adding the water emulsion in the fuel the drastic reduction in the oxides of nitrogen.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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